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[1] This contribution is the extended, peer reviewed version of a paper presented at the conference *THE FUTURE OF THE ITALIAN GEOSCIENCES, THE ITALIAN GEOSCIENCES OF THE FUTURE" held in Milano on September 10-12, 2014.*

# The Quaternary succession of the Bulè and Alpetto valleys (Monviso Massif, Piedmont) as a possible supply for prehistoric jade axes raw material[1]

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## Abstract

This contribution presents a geological mapping of the Quaternary succession of the Bulè and low Alpetto tributary valleys (Po Valley, Piedmont), together with preliminary data on its petrography. The investigated area, covering an altitude range between 3015 and 1485 meters a.s.l., is located in the Monviso Massif Ophiolite Complex, at the contact with marble and calcschist of the Dora-Maira Massif cover.

The Quaternary sequence mainly consists of glacial, outwash, debris and landslide deposits, with local torrential/avalanche and colluvial bodies. The investigation on the petrographic composition of these sediments has allowed to recognize the occasional occurrence of jadeitite boulders, likely exploited during the Neolithic period for axe head production. Four possible jadeitite blocks have been found, one of them is described here for the first time, sizing up to 1 $m^3$. In detail, one of the finds is a Neolithic site of jade polishing in the high Bulè Valley, that was referred to the middle of V millennium B.C. (Allisio, 2012). The jadeitite blocks have been found in the debris (site a), landslide (site b), glacial (site c) and outwash (site d) sediments. The petrographic characterization of the new jadeitite samples, might potentially shed light on the still controversial genesis of these peculiar rocks.

Key words: Monviso Massif, prehistoric jade axes, Quaternary succession, jadeitite

[1] This contribution is the extended, peer reviewed version of a paper presented at the session "Archaeometry andCultural Heritage: the contribution of Geosciences" held during the conference "The future of the Italian Geosciences, the Italian Geosciences of the future" organized by the Società Geologica Italiana and the Società Italiana di Mineralogia e Petrologia, Milano, September 10-12, 2014.

## 1. Introduction

In the Antiquity Museum of Torino several ancient axes made of jadeitite and omphacitite are exposed, related to the Neolithic period (Compagnoni et al. 1995). The petrographic composition of the jadeitite axes, representing the most typical finds, suggests to previous authors a supply from the western Alps, particularly from the Monviso Massif (Compagnoni et al. 2007). The petrographic composition of the jadeitite axes was already studied in detail by previous research and will not be further discussed in this paper. It is possible that the prehistoric man not directly scooped the bedrock, the more difficult to sample because at high altitude and not easily accessible, but used instead some ready boulders contained in the Quaternary sediments located at lower altitude than the source outcrops (Allisio 2012).

What is actually missing is an exhaustive characterization of the nature of Quaternary sediments in which these jadeitite blocks are found. The recognition of the nature of such deposits could eventually led to the discovery of other jadeitite blocks still unknown and to the understanding of the Quaternary glacial and post-glacial evolution of the area.

A detailed mapping of the Quaternary succession of the Monviso sector , however, is still missing. The main goal of the present study is, therefore, to provide the geologic setting of these sediments in the Bulè and Alpetto valleys, the most promising localities for the supply of jadeitite clasts. This research is useful to clarify the location of some boulders and clasts used as raw material for the axe production in the framework of the Quaternary succession of the Bulè and Alpetto Valleys. Another purpose of this study is to make a petrographic analysis of the clasts within the different types of Quaternary deposits, useful to infer possible different lithologies and source outcrops within the different units in the Monviso Massif.

This study represents, therefore, an example of the combined use of both Quaternary geology and petrography, providing a contribute useful to clarify an archeological issue.

## 2. Methods

A detailed geological and geomorphological survey on the field and a traditional and digital analysis of aerial photos were carried out in order to map the Quaternary succession. The distribution of the Quaternary sediments was reported on the Carta Tecnica Regionale (CTR) of the Regional Agency for the Protection of the Environment (A.R.P.A. Piemonte), at the 1:10000 scale. Different units have been distinguished within the Quaternary succession, basing on the sediments facies.

A petrographic analysis of the Quaternary sediments was devoted to the study of representative boulders outcropping on the surface of the studied Quaternary succession, because of lack of outcrops. In order to achieve these results, the most promising boulders were selected in the field on the basis of their mesoscopic petrographic features. Representative thin sections of the selected boulders were studied by means of transmitted polarized light petrographic microscopy. Because a detailed minero-chemical study of the jadeitite is beyond the aim of this paper, only the main petrographic features of the jadeitite are discussed, with particular attention to the newly discovered block (site **d**).

## 3. Finds of jadeitite axes in the Western Alps

The Monviso Massif in the Western Alps is regarded as one of the main production areas of Neolithic axes made with "green stones" (Pétrequin et al. 2005). In particular, the Monviso Massif was recently reported to be especially important for the supply of Neolithic axes made with jadeitite (Compagnoni and Rolfo 2003). Jadeitite outcrops, mostly associated with ultramafic bodies, are extremely rare and the Western Alps is one of the few areas in the world where jadeitite occurrences have been reported so far (Fig. 1). The high specific weight, toughness and hardness of the jadeitite, coupled with its peculiar green color, make this lithology particularly suitable for the building of tools. The archaeological finds suggest that these "green stones" axes have got a wide spread in the Neolithic period, reaching for example all of Western Europe (France, Germany, Spain and England) (Harlow and Sorensen 2005; Fig. 2).

The Monviso jadeitite is macroscopically a generally homogeneous, fine-grained rock, pale green in color and mainly consisting of jadeite (Na-Al-pyroxene). However, it may locally contain irregular cm-sized coarse-grained pockets and veins or even pegmatoidal portions, rich in various minerals as for instance phlogopite, chlorite, garnet (Compagnoni et al. 2007). Genetically, the Monviso jadeitite is considered as the metamorphic equivalent of former trondhjemites, i.e. the final products of the oceanic basalt magmatic differentiation process, originally occurring as dykes cutting across upper-mantle peridotite, later hydrated to serpentinite and subsequently affected by regional metamorphism (Compagnoni et al. 2007).

In the investigated area the jadeitite is associated with the Serpentinite Basal Unit of the Monviso Ophiolite Complex (see Fig. 5). During the Neolithic, and mainly in the 5th millennium BC, the jadeitite was mainly extracted from Quaternary sediments (Allisio 2012). The boulders were then subjected to the action of fire to extract blocks and splinters with smooth surface, later worked with the firing pin.

## 4. Geological features

The investigated area (Fig. 3) is located in the Monviso Massif, in the southern sector of the Western Alps (Fig. 4). In detail, it regards the Bulè and Alpetto valleys, tributaries of the Po Valley. The Monviso Massif is one of the most representative and best preserved ophiolite bodies in the Alps (Monviso Ophiolite Complex, Fig. 5), tectonically emplaced between the underlying continental-derived Dora-Maira thrust units (Dora Maira Calcshist in Fig. 6 ) and the ocean-derived Piemonte Zone metasedimentary units (Piedmont Calcshist in Fig. 6) (Rolfo et al. 2015). As one of the biggest preserved relics of oceanic crust in the Western Alps, it formed during the Mesozoic opening of the Western Alpine Tethys and subsequently underwent high-pressure (eclogitic) metamorphism during the Alpine subduction (e.g. Lombardo et al,1978). The Monviso Massif encompasses the whole lithological spectrum of the Piemonte-Ligurian ophiolites, with metamorphic rocks derived from former peridotite, Mg-Al-rich and Fe-Ti-rich gabbro, dolerite, basalt, as well as cover sediments (Rolfo et al. 2014).

The studied area shows an extensive Quaternary cover, referred to the upper Pleistocene (glacial and outwash deposits) and Holocene (debris, landslide, torrential/avalanche and colluvial deposits). The subglacial sediments (2 in Fig. 6) are instead very widespread in the entire valleys. They form large sectors of both sides of the glacial valleys, forming typical rounded morphologies. They consist of an abundant silty-sandy matrix, over-consolidated, incorporating few, prevalently rounded, boulders.

The supraglacial sediments (2 in Fig. 6) are also very abundant in the intermediate and low stretches of the valleys, forming numerous moraines connected to very different configurations of the Bulè and Alpetto glaciers. They consist of several boulders highly variable in size, between few centimeters to about a thousand of meters in size.

The petrographic composition of both facies of the glacial sediments is very heterogeneous, consisting of a mixture of the various lithologies outcropping in the whole basin (eclogite, metagabbro, prasinite, serpentinite and calcschist with subordinate quartzite and marble). The abundance of the various lithotypes of the supraglacial sediments forming the moraines was investigated in detail. Jadeitite boulders and clasts resulted very subordinate with respect to gabbro, eclogite and prasinite, reflecting the abundance of these rocks in the source outcrops at the head of the valleys.

The outwash sediments are mainly located in the low stretches of the valleys, forming wide flat outwash fans (2 in Fig. 6). They consist of prevalently rounded boulders, between few centimeters to 1 meter in size, mixed to a prevalently coarse sandy matrix. The petrographic composition of these sediments is even heterogeneous, also representative of the whole basin, due to their origin by re-sedimentation of the glacial sequence.

The debris sediments are particularly abundant in the upper stretch of the Bulè and Alpetto valleys forming wide, very steep, debris fans (3 in Fig. 6). These sediments consist of angular rock fragments, between 1 $dm^3$ and 1 $m^3$ in size. The petrographic features of fragments are relatively monotonous, and closely linked to the bedrock forming the overhanging cliffs. The occurrence of numerous rock glaciers of various size indicates that the debris sediments are frequently re-moved, due to the interstitial ice, forming peculiar set of arched landforms.

The landslide sediments are located in the upper stretches of the valleys, reworking both the bedrock as well as the glacial and debris succession (5 in Fig. 6). The landslide bodies have a wide between some thousands of $m^2$ and about 1 $km^2$. The sediments consist of boulders highly variable in size, mixed to an abundant, soft sandy-silty matrix. The petrography of fragments is prevalently monotonous, linked to the bedrock forming the detaching niches, with the exception of the clasts deriving from the reworking of glacial deposits.

Few small bodies of fluvial, torrential/avalanche, forming small fans, and colluvial sediments are located in various places of the studied area (4, 6 and 7 in Fig. 6).

## 5. **Jadeitite remains in the studied area**

Regarding the Quaternary succession as a possible source for the prehistoric jadeitite axes, we report the finds in the quaternary sediments of the studied area. Among them, an angular block of jadeitite (ca. 1 $m^3$ in size) is associated to debris sediments on the northern side of Punta Rasciassa (**site a** in Figs. 6, 7 and 8) and is already reported by Compagnoni et al. (2007) and Pétrequin et al. (2012). Some centimetric fragments of jadeitite and omphacitite were found, probably forming a larger boulder associated to landslide sediments, in the upper Bulè Valley (**site b** in Figs. 6, 7 and 8). Among those studied in this paper, this is the only site where, according to Pétrequin et al. (2012), the fragments seem to be worked by the prehistoric man. Another sub-angular pebble (ca. 1 $m^3$ in size) macroscopically resembling jadeitite, was found in the low Alpetto Valley in the supraglacial sediments (**site c** in Figs. 6, 7 and 8) and was also reported by Pétrequin et al. (2012). The petrographic analysis of this sample, however, showed that it consists of a fine-grained eclogite. Finally, during the present survey one sub-rounded pebble of jadeitite (ca. 1 $m^3$ in size) was found associated to outwash sediments in the lower Bulè Valley (**site d** in Figs. 6, 7 and 8) (Avondetto 2014).

It is worth-noting that this new finding is, to our knowledge, the only jadeitite block associated to a Quaternary deposit of glacial nature (outwash sediments), being the other two (**site a** and **b** in Figs.

6 and 7) associated to debris and landslide sediments, respectively. This implies that the jadeitite block of site (**d**) experienced a longer-distance transportation from the source outcrop than the other blocks. The detailed study of the petrography of the outwash sediments (as well as subglacial and supraglacial sediments) downstream with respect to the present finding could potentially led to the discovery of other jadeitite blocks, even more accessible than that of site (**d**).

The petrographic features of the Monviso jadeitite blocks are remarkably homogeneous and similar to those described by Compagnoni et al. (2007). In hand specimen, the jadeitite is a very pale grass green, fine-grained massive rock (site a Fig. 9A). The jadeitite locally contains irregular centimeter-sized, coarse-grained, phlogopite-rich pockets and veins. Locally, coarse-grained portions with peculiar pegmatoid grain size occur and consist of centimetre-sized crystals of bright green clinopyroxene (site d Fig. 9B) and light grey chlorite flakes. Most jadeitite blocks are mantled by darker retrogression margins from 10 to 20 cm thick (site a in Fig. 9C).

Under the microscope, the jadeitite is heterogeneous, being formed by variously distributed: 1) portions mainly consisting of clear, inclusion free, clinopyroxene; 2) portions where clinopyroxene is associated with up to about 10 vol.% of rutile; 3) portions with dusty clinopyroxene, crowded of micron-sized inclusions of titanite, and 4) portions with coarser grained veins and pockets of phlogopite + Mg-chlorite. In all portions, the clinopyroxene occurs as aggregates of interlocked blocky crystals less than 0.5 mm across, which systematically show, from core to rim, a strong and sharp compositional zoning. Locally in the fine grained matrix, coarser clinopyroxenes up to several mm across occur with a cloudy core, crowded with very fine grained oriented inclusions (Fig. 11), which appear to be relict portions, most probably derived from former igneous crystals. Distinctive accessory minerals are zircons, few micrometers across, commonly showing a blocky prismatic shape.

Veins and intergranular pockets consist of randomly oriented clusters of idioblastic clinopyroxene surrounded by xenoblastic albite or phlogopite and Mg-chlorite. A light purple allanite locally occurs as poikiloblasts in both the rock matrix and the veins.

The portion with pegmatoid grain-size consists of greenish clinopyroxene domains and chlorite ± phlogopite, which may include clinopyroxene needles. Very few small garnets (<1 mm) locally occur, which are partially retrogressed to chlorite.

## 6. Preliminary conclusions

The geological surveys of the Bulè and low Alpetto tributary valleys show the wide distribution of the Quaternary succession, consisting of glacial, outwash, debris and landslide deposits with local torrential/avalanche and colluvial bodies. The investigation on the petrographic composition of these sediments has allowed to recognize the occasional occurrence of jadeitite boulders, likely exploited during the Neolithic period for axe head production (Allisio 2012). Four possible jadeitite blocks have been found, one of them for the first time, sizing up to 1 $m^3$ supplied by debris (site a), landslide (site b), supraglacial (site c) and outwash (site d) sediments. The petrographic analyses confirm that three of them (site a, b, d) are jadeitite and the fourth is an eclogite (site c).

The systematic search of the jadeitite boulders being part of the Quaternary sediments and their petrographic characterization allow us to draw some preliminary results. Few boulders, though very limited in number, consist of jadeitite, thus confirming the occurrence of this peculiar lithology in the Monviso Ophiolite Complex and its possible use by the prehistoric man.

However, the different finds of jadeitite reported in this study have clearly a different Quaternary setting which can be directly related to the interpretation of their source areas. For instance, the jadeitite boulders in the debris and landslide sediments obviously derive by the cliffs directly above, while the jadeitite boulders in the glacial and outwash sediments can instead supply from very far glacial cirques at the head of the valleys.

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## Figure captions

Figure 1 - Distribution of jadeitite outcrops in the world (modified from Harlow and Sorensen 2005).

Figure 2 - Distribution of green stones axes (jadeitite and omphacitite ) in Europe (modified from Pétrequin et al. 2012).

Figure 3 - Panoramic view of the Monviso from NNE (Pian della Regina).

Figure 4 - Location of the Monviso area (red star) in the framework of the Western Italian Alps.

Figure 5 - Geological cross section of the metamorphic units in the Monviso Massif. CB: basal calcschist and marl; USB: basal serpentinite Unit; USL: Lago Superiore Unit; UVM: Viso Mozzo Unit; UPG: Passo Gallarino Unit; UCT: Costa Ticino Unit; UV: Vallanta Unit; CO: calcschist (modified from Lombardo et al. 1978).

Figure 6 - Simplified geological map of the Quaternary succession of the Bulè and Alpetto valleys. The location of the collected jadeitite (sites **a**, **b**, **d**) and eclogite finds (site **c**) are also reported (red and green stars, respectively).

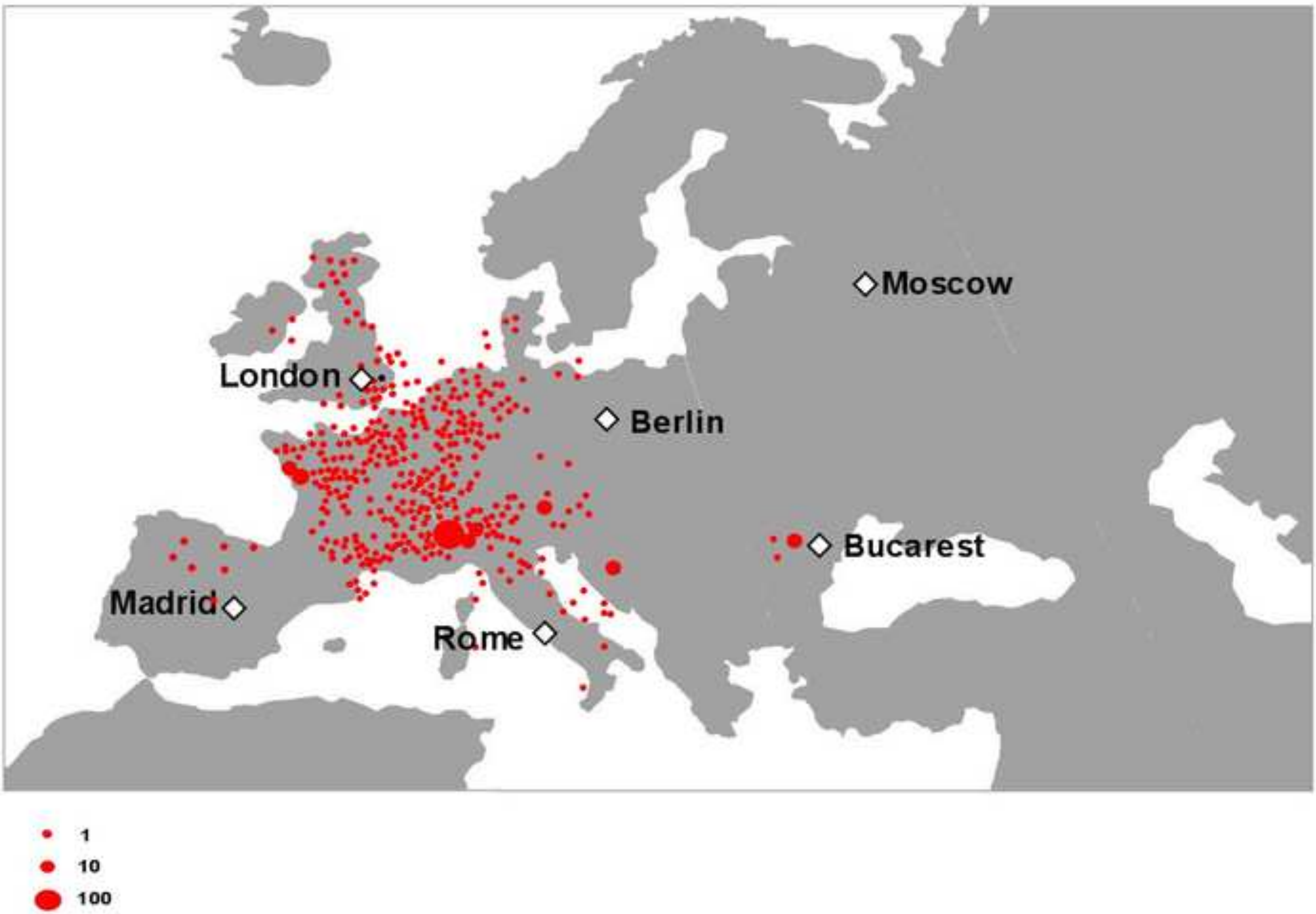
Figure 7 - Location of the collected jadeitite (red star) and eclogite (green star) in the Alpetto and Bulè valleys. The sites (**a**, **b**, **c**, **d**) correspond to the sites in Figs. 8 and 9.

Figure 8 - Jadeitite and omphacitite/eclogite occurrences in the studied area. (a) Site **a** on the northern flank of Punta Rasciassa (jadeitite). (b) Site **b** in the upper Bulè Valley (jadeitite and omphacitite); (c) Site **c** in the low Alpetto valley (fine-grained eclogite); (d) Site **d** in the low Bulè Valley (jadeitite).

Figure 9 - Outcrop appearance of the studied jadeitite blocks. (a) Very pale grass green, fine-grained massive jadeitite (site **a**). (b) Jadeitite with coarse-grained portion consisting of bright green clinopyroxene (site **d**). (c) Jadeitite block mantled by darker retrogression margin mainly consisting of chlorite (site **a**).

Figure 10 - Microstructural features of jadeitite in the low Bulè Valley (site **d**) at the optical microscope (a, c: Plane Polarized Light; b, d: Crossed Polarized Light). Most of the jadeite crystals show a cloudy core, crowded with very fine grained oriented inclusions.

Distribution of jadeitite outcrops in the world (modified from Harlow and Sorensen, 2005).
Click here to download Figure: Fig. 1.jpg



Distribution of green stones axes (jadeitite and omphacitite ) in Europe (modified from Pétrequin et al., 2012).
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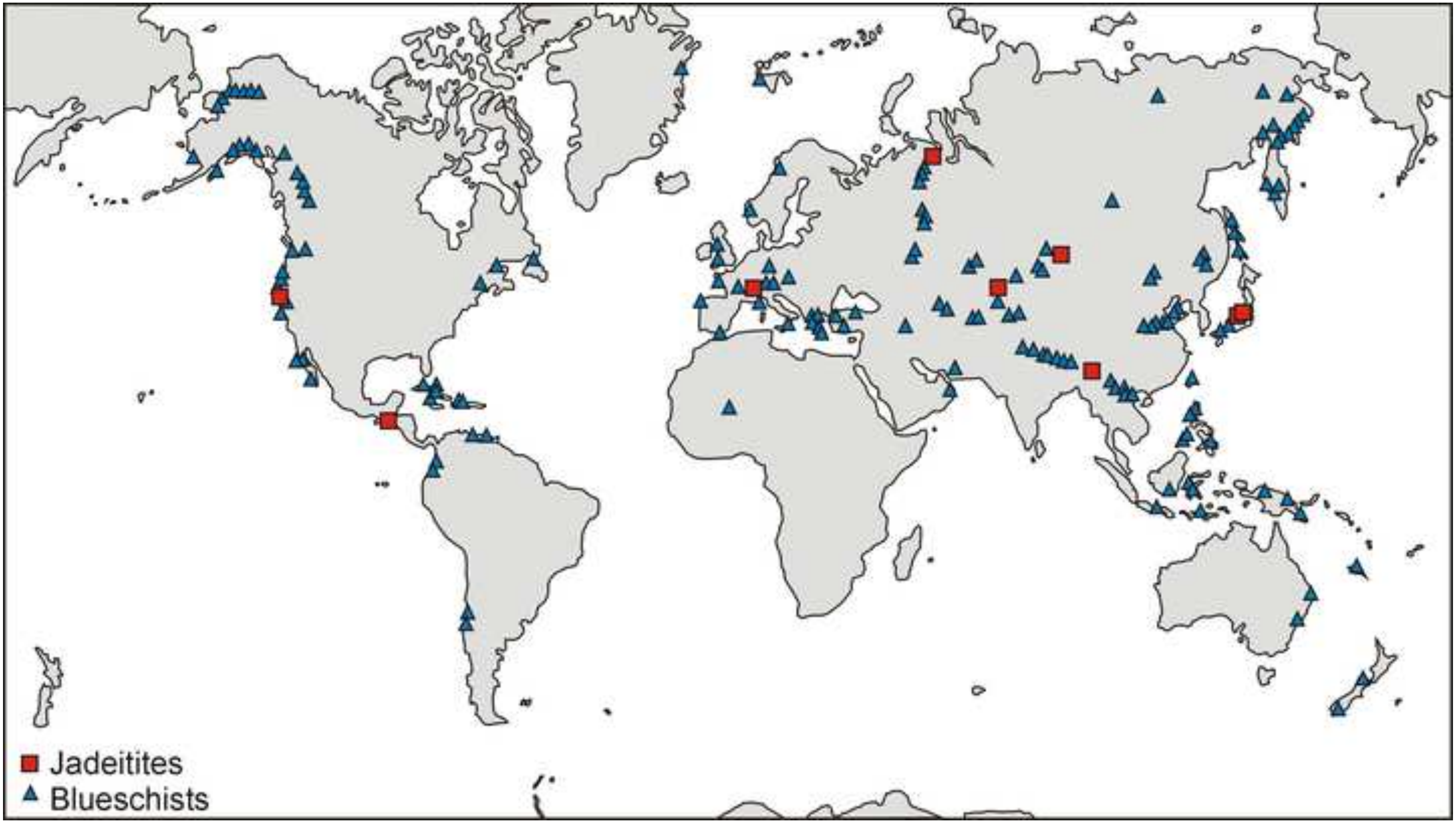

Panoramic view of the Monviso from NNE (Pian della Regina).
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Location of the Monviso area (red star) in the framework of the Western Italian Alps.
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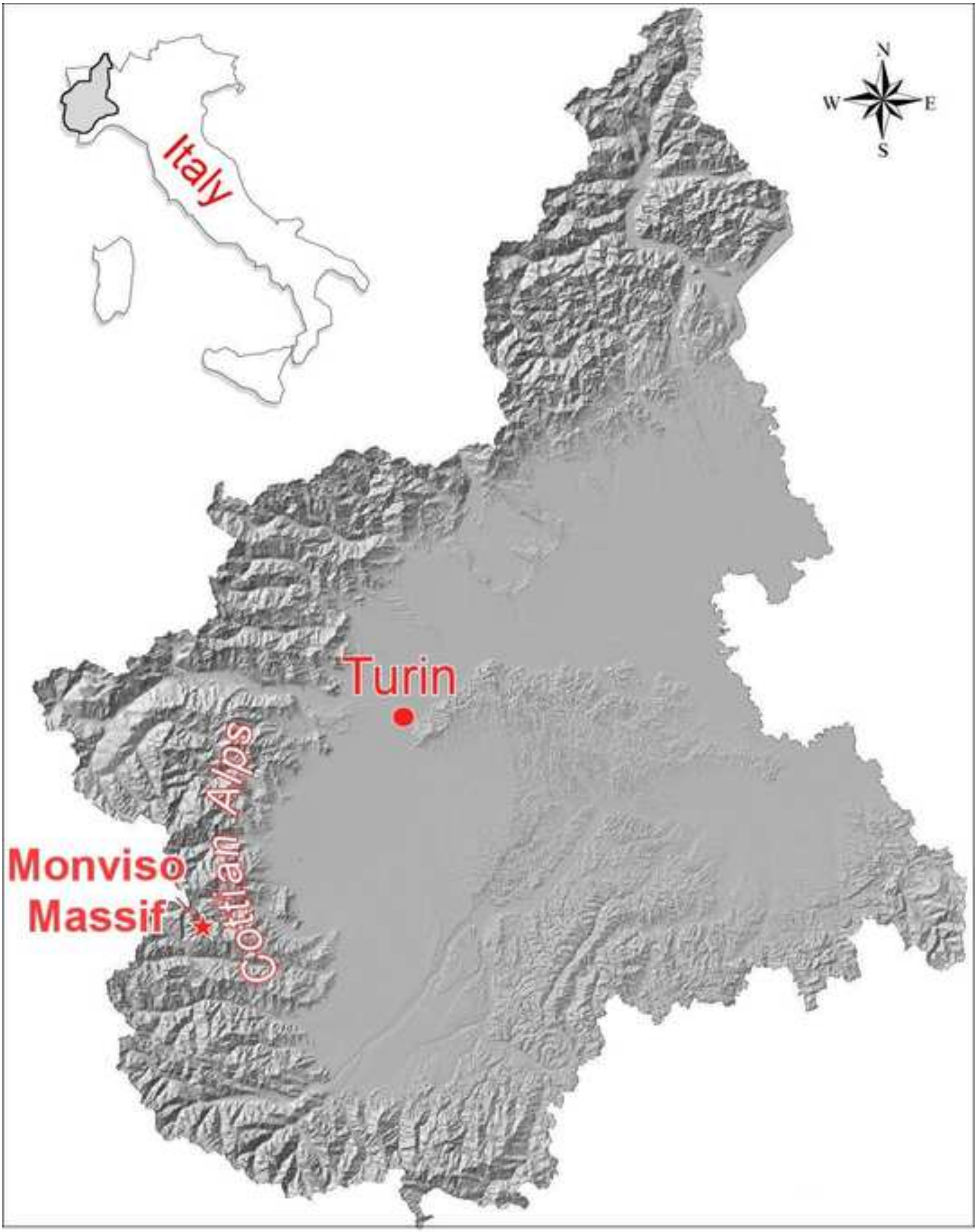

Geological cross section of the metamorphic units in the Monviso Massif. CB: basal calcschist and marl; USB: basal serpentinite Unit; USL: Lago Superiore Unit; UVM: Viso Mozzo

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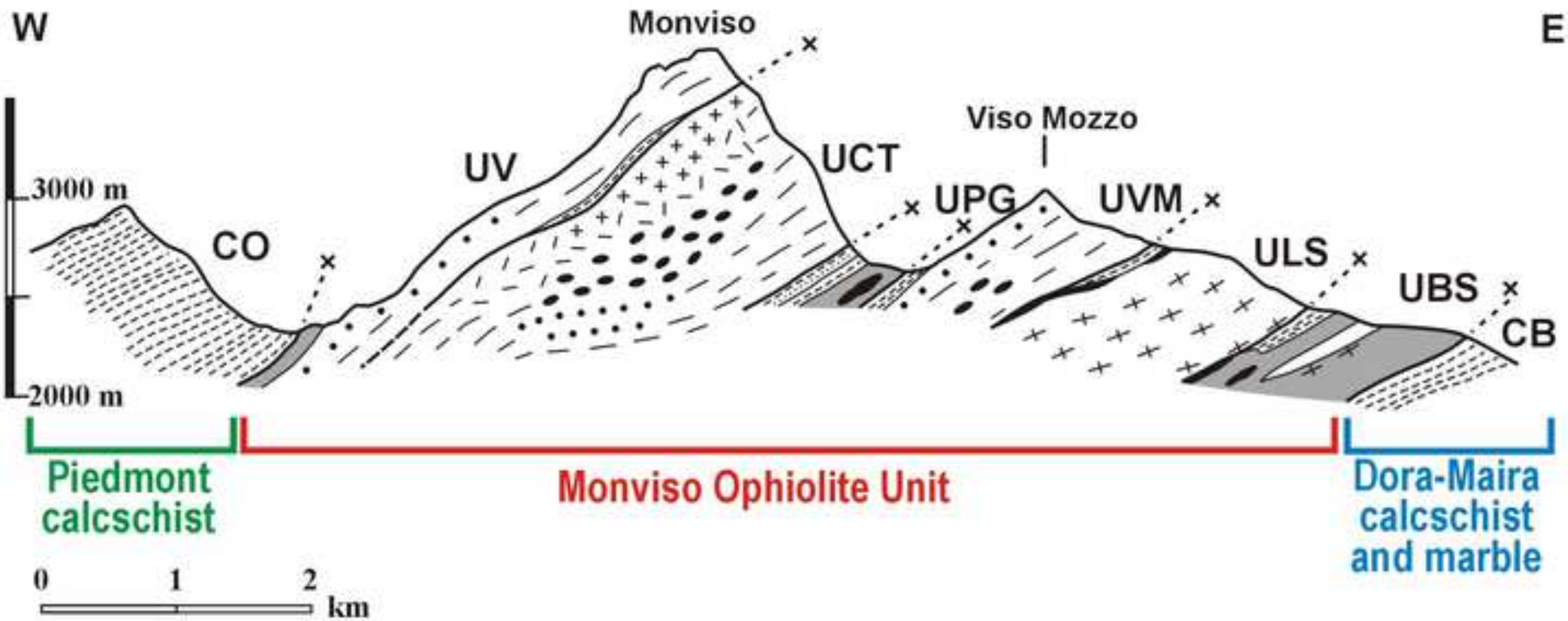

Simplified geological map of the Quaternary succession of the Bulè and Alpetto valleys. The location of the collected jadeitite (sites a, b, d) and eclogite finds (site

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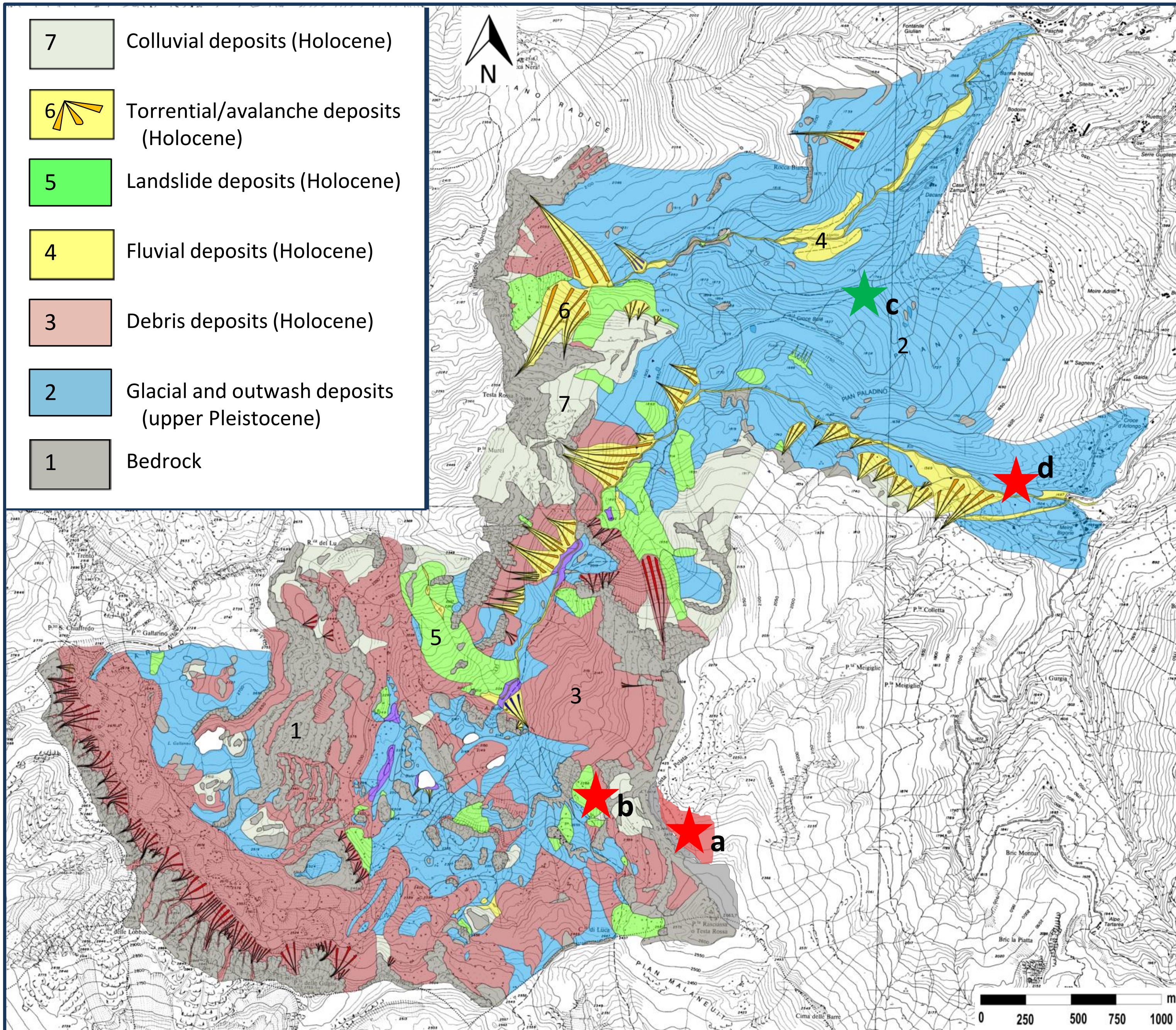

Location of the collected jadeitite (red star) and eclogite (green star) in the Alpetto and Bulè valleys. The sites (a, b, c, d) correspond to the sites in Figs. 8 and 9.
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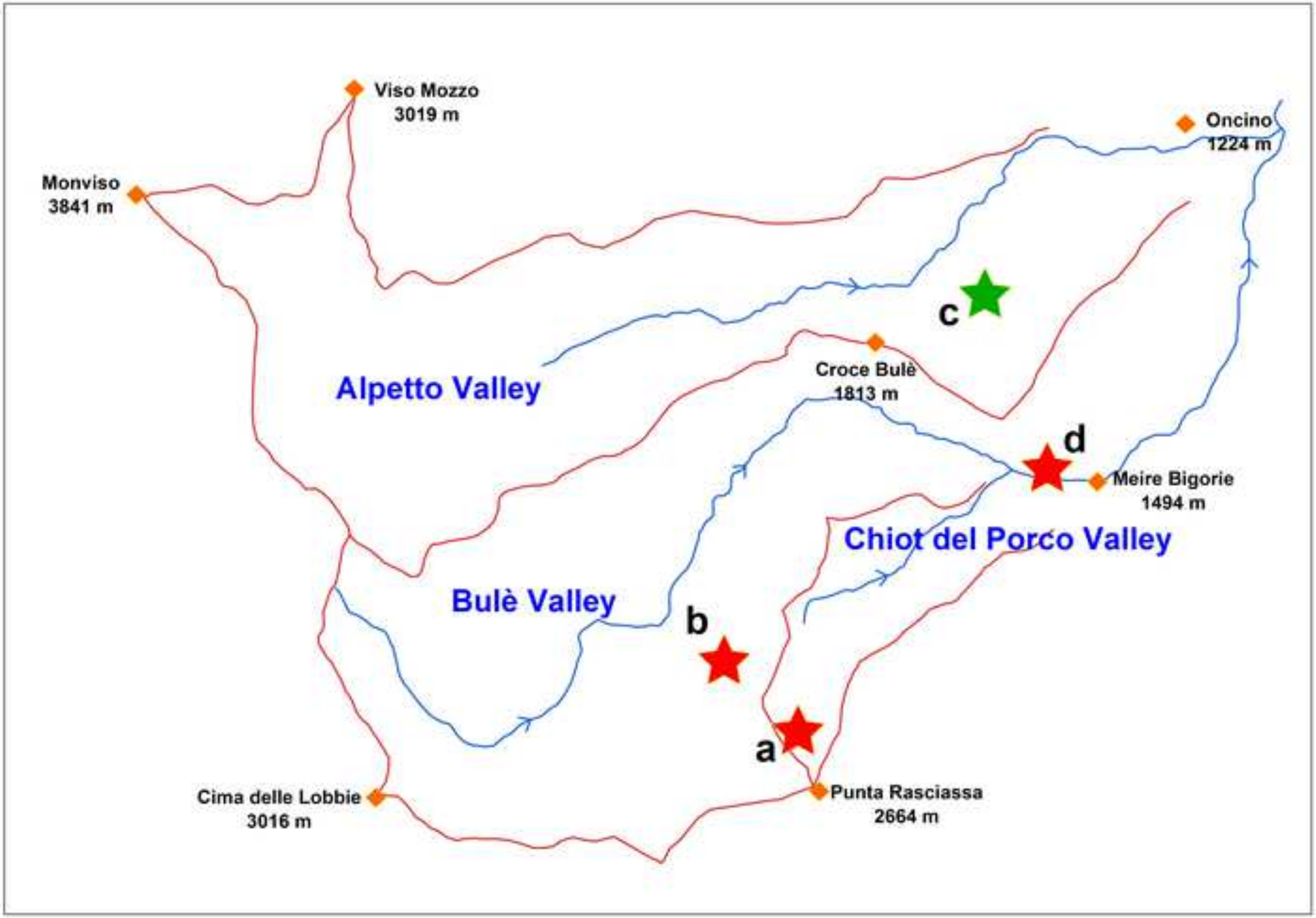

Jadeitite and omphacitite/eclogite occurrences in the studied area. (a) Site a on the northern flank of Punta Rasciassa (jadeitite). (b) Site b in the upper Bulè Valley (jadeitite and o

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Jadeitite and omphacitite/eclogite occurrences in the studied area. (a) Site a on the northern flank of Punta Rasciassa (jadeitite). (b) Site b
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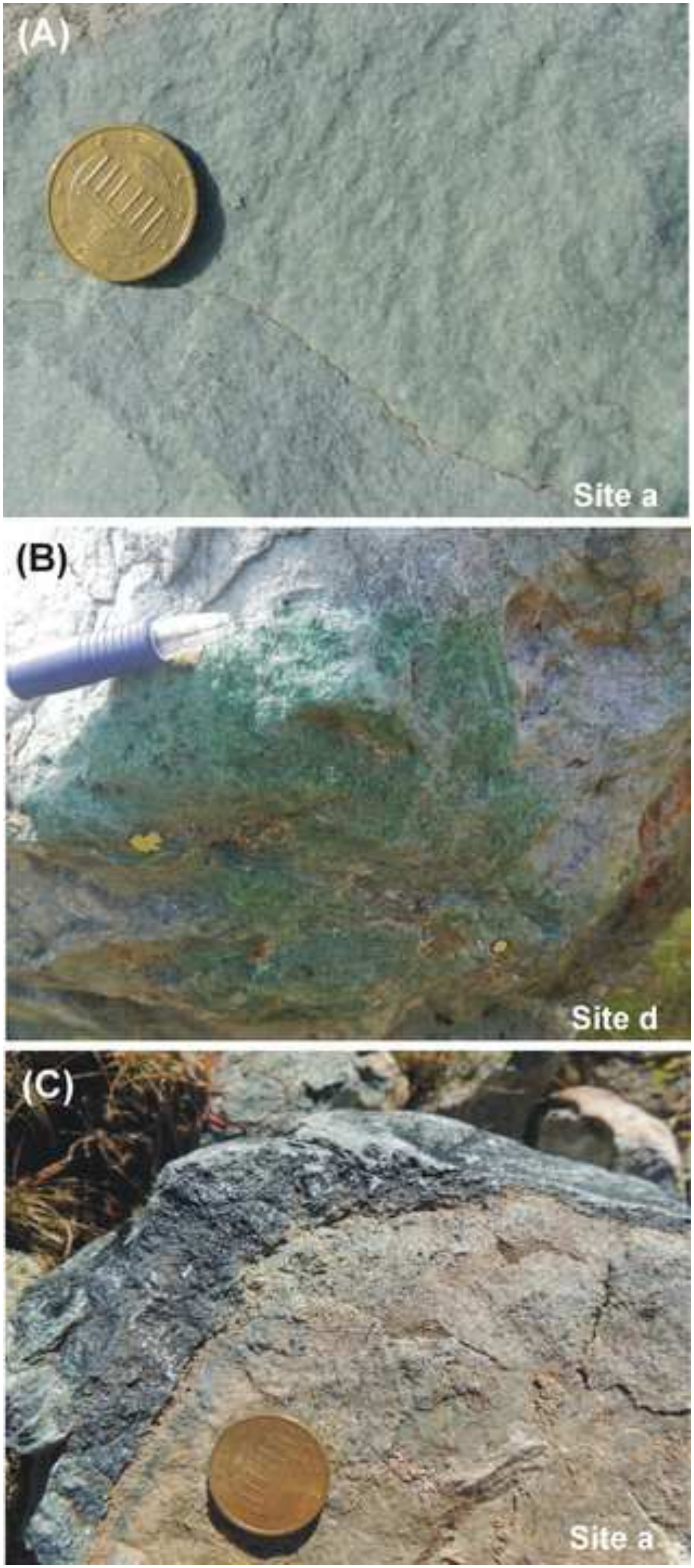

Microstructural features of jadeitite in the low Bulè Valley (site d) at the optical microscope (a, c: Plane Polarized Light; b, d: Crossed Polarized Light). Most of the jadeite crystals s

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